Instruction Manual

012-08489B

# Brewster's Angle Accessory

## Model No. OS-8170A

PASCO®

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# Brewster's Angle Accessory

**Model No. OS-8170A**

## Equipment

| Included Equipment | Model Number |
|---|---|
| 1. Polarizer Assembly (1 lens holder and 2 round polarizers) | 003-09784 |
| 2. Analyzing Polarizer (1), Lens Mount (1), and Pivot Plate Assembly (1) | 003-08332 |
| 3. Beam Splitter (1) | OS-8171 |
| 4. Semi-circular Acrylic Lens (1) ("D" Lens) | 003-08545 |

| Additional Equipment Required - Option 1 | Model Number |
|---|---|
| Educational Spectrophotometer Accessory* | OS-8537* |
| • Collimating Slits | |
| • Spectrophotometer Base | |
| High Sensitivity Light Sensor (2) | PS-2176 or CI-6604 |
| Rotary Motion Sensor (1) | PS-2120 or CI-6538 |
| Aperture Bracket (2) | OS-8534A |
| Optics Bench, 60 cm (2) | OS-8541 |
| Basic Optics Diode Laser (1) | OS-8525A |
| **OR (see next page)** | |

*The Accessory includes unlisted items that are not used for the experiments.

| **Additional Equipment Required - Option 2** | **Model Number** |
|---|---|
| Educational Spectrophotometer System | OS-8539 |
| • Educational Spectrophotometer Accessory | OS-8537 |
| • Optics Bench, 60 cm | OS-8541 |
| • High Sensitivity Light Sensor | CI-6604 |
| • Rotary Motion Sensor | CI-6538 |
| • Aperture Bracket | OS-8534A |
| Basic Optics Diode Laser | OS-8525A |
| Optics Bench, 60 cm | OS-8541 |
| High Sensitivity Light Sensor | CI-6604 |
| Aperture Bracket | OS-8534A |

| **PLUS** | |
|---|---|
| Patch Cord (2) | See PASCO web site* or catalog |
| PASCO computer interface | See PASCO web site* or catalog |
| PASCO data acquisition software | See PASCO web site* or catalog |
| **Suggested Additional Equipment** | |
| Green Diode Laser | OS-8458 |

*www.pasco.com

Complete packages of all the equipment and sensors are available from PASCO. Choose the EX-9919A Brewster's Angle Experiment (ScienceWorkshop) if you want to use ScienceWorkshop sensors or choose the EX-9965A Brewster's Angle Experiment (PASPORT) if you want to use PASPORT sensors.

PASCO's Brewster's Angle Accessory is designed to be used with the Educational Spectrophotometer System (OS-8539). In addition to the Educational Spectrophotometer System, the experiments need the Basic Optics Diode Laser (OS-8525A), and one or more of each of the following: Optics Bench (OS-8541), Aperture Bracket (OS-8534A), and High Sensitivity Light Sensor. A PASCO computer interface, and PASCO data acquisition software are also required for the experiments.

**NOTE:** A folder for the Brewster's Angle experiment is available as a ".ZIP" file to download from the PASCO web site. Go to the page that shows the EX-9919A or EX-9965A Brewster's Angle Experiment and click "Download". The folder contains DataStudio setup files and sample data files for ScienceWorkshop and PASPORT sensors, and Microsoft Word ".DOC" files for the experiment procedure.

# Introduction

The Brewster's Angle Accessory (OS-8170A) is used in optics for studying the polarization of reflected light and for determining Brewster's angle. The accessory consists of a lens holder with two polarizers, a rotating platform (Pivot Plate Assembly) with a semi-circular "D" lens, an analyzing polarizer, and a beam splitter.

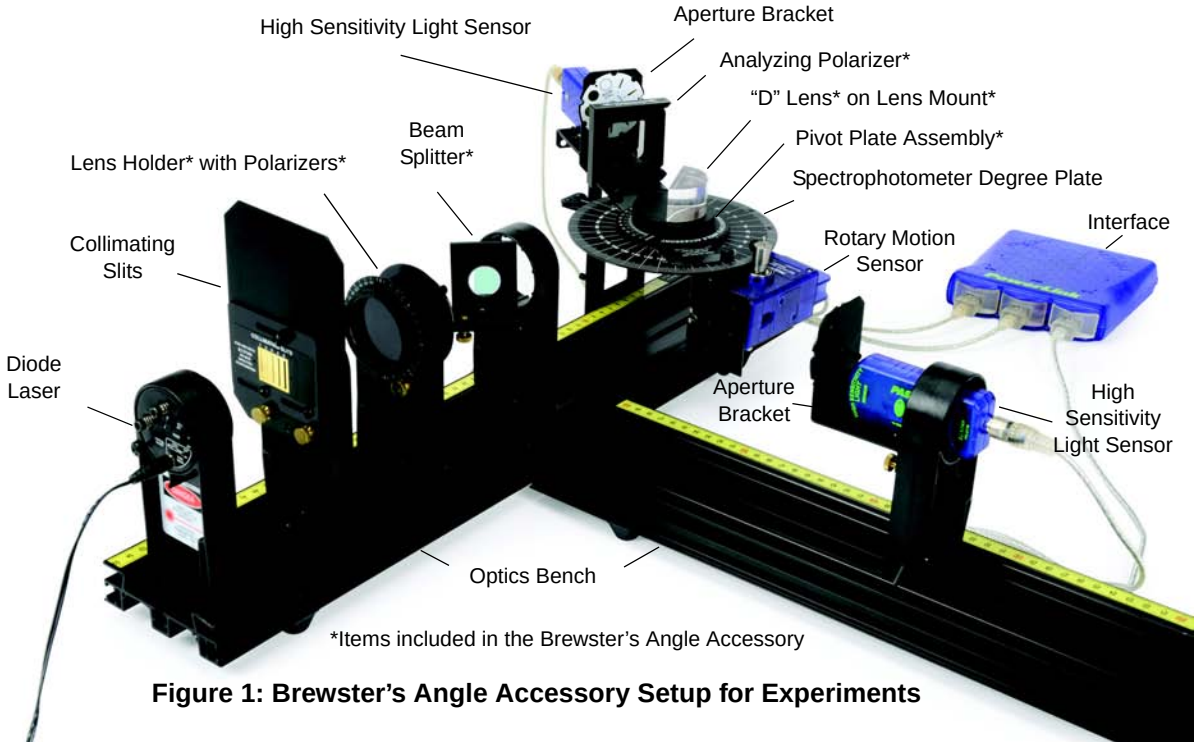



**Figure 1: Brewster's Angle Accessory Setup for Experiments**

When light reflects off a nonconducting material, the reflected light is partially polarized. The amount of polarization depends on the incident angle and the index of refraction of the reflecting material. *The incident angle that gives the maximum polarization is called Brewster's angle.*

Light from a Diode Laser is reflected off the flat side of an acrylic semi-circular ("D") lens. The reflected light passes through an analyzing polarizer and is detected by a Light Sensor. The angle of incidence is measured by a Rotary Motion Sensor mounted on the Spectrophotometer Base. The intensity of the reflected polarized light versus the incident angle is graphed to determine the angle at which the light intensity is a minimum. This is Brewster's angle, which is used to calculate the refraction index of acrylic.

## Theory

When unpolarized light reflects off a nonconducting surface, it is partially polarized parallel to the plane of the reflective surface. There is a specific angle called Brewster's angle at which the light is 100% polarized. This occurs when the reflected ray and the refracted ray are 90 degrees apart.

According to Snell's Law,

$$n_1 \sin\theta_1 = n_2 \sin\theta_2 \qquad (1)$$

where **n** is the index of refraction of the medium and θ is the angle of the ray from the normal.

When the angle of the incident ray is equal to Brewster's angle, $\theta_P$,

$$\mathbf{n_1 \sin\theta_P = n_2 \sin\theta_2} \qquad (2)$$

and since $\theta_P + \theta_2 = 90^o$,

$\theta_2 = 90^o - \theta_P$, and

$$\mathbf{\sin\theta_2 = \sin(90^o - \theta_P) = \sin 90^o \cos\theta_P - \cos 90^o \sin\theta_P = \cos\theta_P}$$

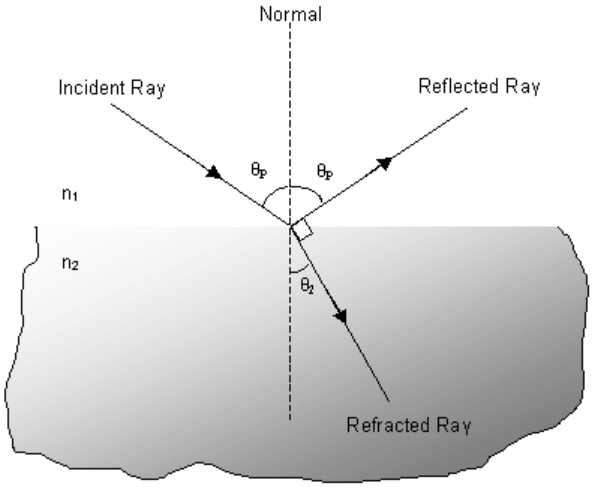



**Figure 2: Polarization of Unpolarized light**

Substituting for $\sin\theta_2$ in Equation (2) gives $\mathbf{n_1 \sin\theta_P = n_2 \cos\theta_P}$

Therefore, $\dfrac{\mathbf{n_2}}{\mathbf{n_1}} = \tan\theta_P$ (3)

# Setup Instructions

## Assemble the Spectrophotometer Base

**1.** Attach the Spectrophotometer Base at one end of an Optics Bench.

**2.** Attach the Spectrophotometer Degree Plate to the Base, but align the Degree Plate "backwards"; that is, line up the *180 degree mark* on the Degree Plate with the index line on the Base.

**3.** Attach the Spectrophotometer Arm to the Degree Plate.
(For instructions on setting up the Spectrophotometer parts, see the *Educational Spectrophotometer Manual.* You can download a PDF file of the manual from the PASCO web site. Go to the page that shows the OS-8539 and click the "Manual" tab.)

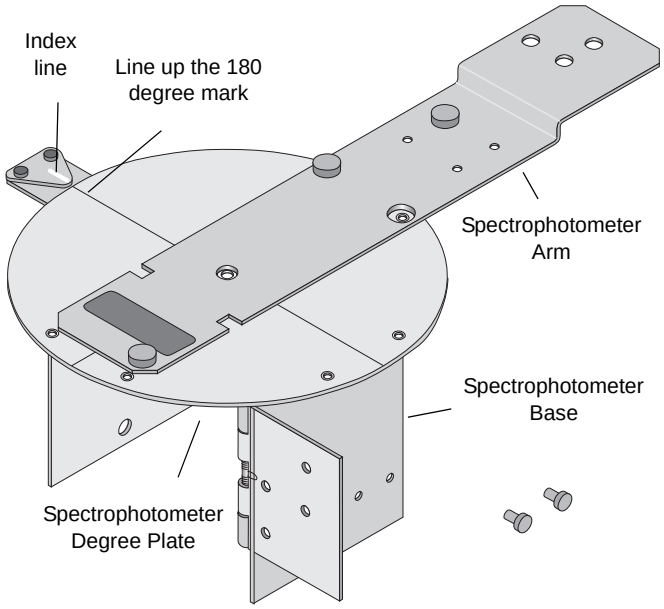



**Figure 3: Assemble the Spectrophotometer Base, Degree Plate, and Arm**

**4.** Mount a High Sensitivity Light Sensor to an Aperture Bracket and attach the Aperture Bracket/Light Sensor to the Spectrophotometer Arm.)

**5.** Mount the Rotary Motion Sensor to the upper holes on the hinge of the Spectrophotometer Base. Mount the Spindle on the shaft of the Rotary Motion Sensor so that the bigger diameter of the spindle is against the edge of the Spectrophotometer Degree Plate (see Figure 4).

**6.** Connect a patch cord from an electrical ground to a bare piece of metal on the Spectrophotometer Base, as instructed by your teacher.

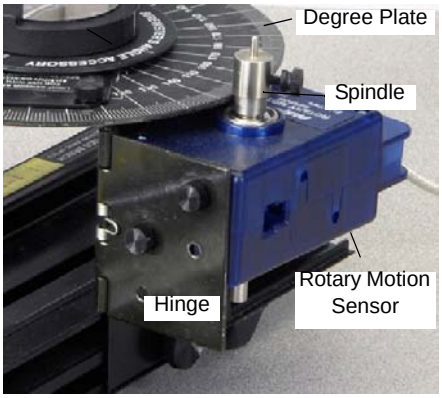



**Figure 4: Mount the Rotary Motion Sensor to the Base**

### Attach the Pivot Plate and Lens Mount

**1.** Screw the Pivot Plate into the threaded hole in the center of the Spectrophotometer Degree Plate.

**2.** Screw a wing nut onto the threaded post of the Pivot Plate that extends below the Spectrophotometer Base.

**3.** Turn the Pivot Plate so that the index mark at the edge of the plate above the "N" in the word ANGLE is aligned with the zero degree mark on the Spectrophotometer Degree Plate.

**Note**: Make sure that the Pivot Plate is not screwed down too tightly against the Degree Plate. The Spectrophotometer Arm should be able to rotate freely and the Pivot Plate should remain stationary as the Spectrophotometer Arm is moved. (Screw the Pivot Plate *almost* all the way down and then tighten the wing nut under the Spectrophometer Base.)

**4.** Place the Lens Mount on the Pivot Plate so that the hole in the bottom of the lens mount matches the post on the pivot plate.

**5.** The Lens Mount has two vertical index marks. For reflected light, use the mark that is on the side with the higher step. Line up the index mark with the zero degree angle on the edge of the Pivot Plate that is closest to the laser.

(**Note**: The other mark can be used for transmission studies in a Snell's Law experiment.)

## Align the Laser Beam

**1.** Put a Laser Diode on the end of the bench opposite to the Spectrophotometer Base.. Connect the laser's power supply to a grounded electrical outlet and plug the power cord into the laser. Turn on the laser (the ON-OFF switch is on the back of the laser).

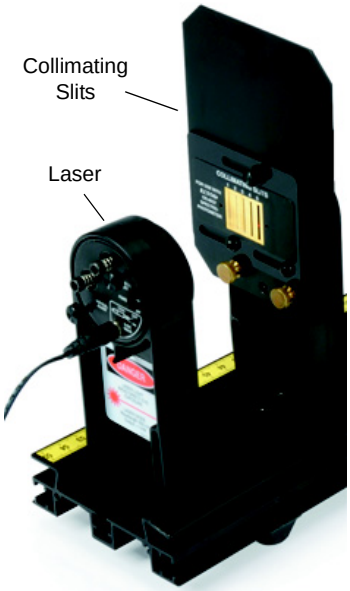



**Figure 5: Laser and Collimating Slits on bench**

**WARNING:** Do not look directly into the beam of the laser light source or reflected light from the laser light source, such as from a mirror. Although the laser used in this experiment is of low power, looking directly into the laser light source or its reflected light from a mirror could cause eye damage. To avoid eye injury, do not look directly into the laser beam and wear laser protective goggles. For more information about laser safety, see Appendix B of this manual.

**2.** Set the Spectrophotometer Arm so that 180 degrees on the Degree Plate is next to the index mark. Set the Aperture Bracket disk to slit #5. Use the x-y adjustment knobs on the back of the laser to aim the laser beam at the center of Aperture Bracket slit #5.

**3.** Place the Collimating Slits on the optics bench and adjust the slit position on the Collimating Slits so that the laser beam passes through slit #5 and also still shines on slit #5 on the Aperture Bracket disk (see Figure 5).

**4.** Adjust the Brewster's Lens Mount so that the index line on the higher step of the Lens Mount is aligned with the zero mark on the Pivot Plate.

**5.** Place the "D" Lens on the lower step of the Lens Mount with the flat side of the lens against the edge of the higher step. If the laser beam is not still centered on slit #5 of the Aperture Bracket, adjust the "D" Lens side-to-side until the laser beam shines on slit #5. Make sure the "D" Lens is firmly against the step.t

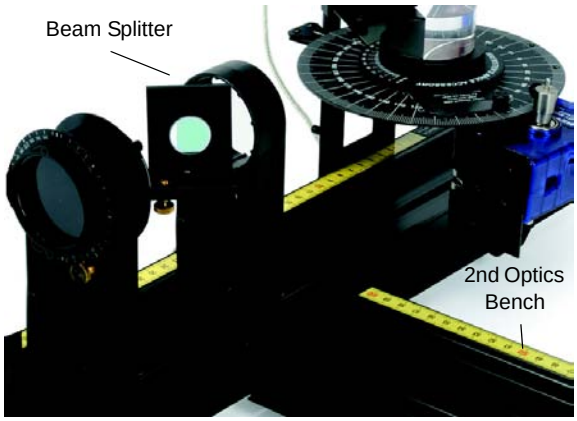



**Figure 6: Mount the Beam Splitter**

**6.** Mount he Beam Splitter on the bench near the center of the bench. Check that the transmitted laser beam still illuminates the #5 slit on the Aperture Bracket on the Spectrophotometer Arm. If necessary, loosen the adjustment screws on the Beam Splitter holder and move the holder to align the laser beam with slit #5 on the Aperture Bracket disk.

## Controlling the Laser Intensity

**1.** Place the second optics bench at right angles to the first optics bench at the spot where the Beam Splitter is mounted.

**2.** Mount the second High Sensitivity Light Sensor on an Aperture Bracket, and attach the Aperture Bracket to a Lens Holder. Set the disk on the Aperture Bracket to slit #5.

**3.** Mount the Light Sensor/Aperture Bracket at the far end of the second optics bench (see Figure 1). Connect a patch cord between an electrical ground and a piece of bare metal on the Aperture Bracket.

**NOTE**.: The second High Sensitivity Light Sensor is used to compensate for the variability of the incident laser beam intensity (see Figure 7). The second light sensor on the optics bench measures the relative incident light intensity (from the Beam Splitter) while the light sensor on the Spectrophotometer Arm simultaneously measures the reflected light intensity (from the "D" Lens through the Analyzing Polarizer).

Any fluctuations in intensity can be normalized by dividing the reflected light intensity by the relative incident light intensity.

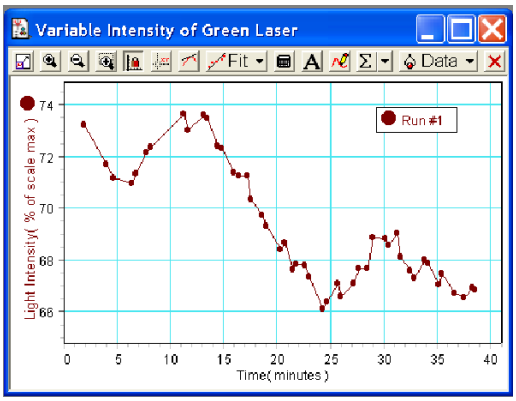



**Figure 7: Variability of Green Laser**

**4.** Adjust the position of the second optics bench as needed until the reflected laser beam from the Beam Splitter travels to slit #5 on the Aperture Bracket disk in front of the second Light Sensor.

**5.** If you need to re-adjust the Beam Splitter, make sure that the laser beam is still aligned with the first High Sensitivity Light Sensor.

**6.** Snap the round Polarizers into both sides of the Lens Holder, and mount the Lens Holder on the bench between the Collimating Slits and the Beam Splitter. The Polarizers help control laser intensity.

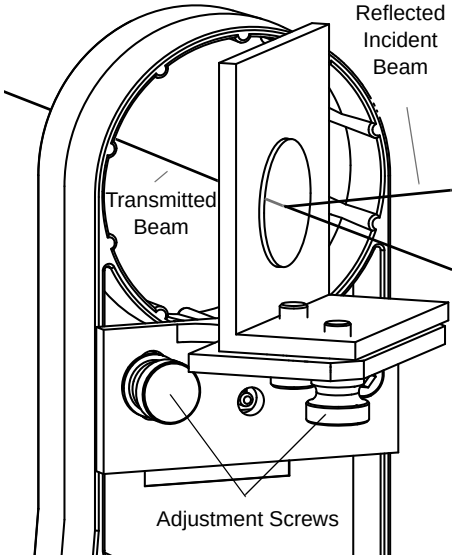



**Figure 8: Adjust the Beam Splitter as needed**

**7.** Rotate the second polarizer (farthest from the laser) to 45 degrees (the indicator is the bottom lip on the lens holder) and lock it in place by tightening the brass screw. The first polarizer (closest to the laser) is used throughout the experiment to adjust the light level. Since the ratio of reflected light to incident light is being measured, better data will be obtained if the incident light level is kept above 50%.

8. The square Analyzing Polarizer (see Figure 9) has its transmission axis marked. Position the Analyzing Polarizer with its label on top and with its axis horizontal.

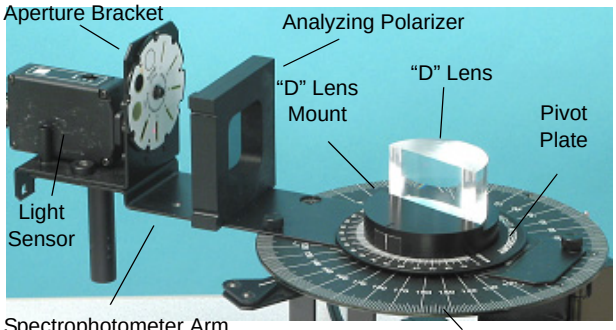



**Figure 9: Analyzing Polarizer and "D" Lens**

**NOTE:** When the Analyzing Polarizer is horizontal, the light passing through the polarizer is the horizontal component (perpendicular to the "D" lens surface) of the light reflected from the flat surface of the "D" lens. In this orientation, the Analyzing Polarizer is blocking the light that is polarized parallel to the flat surface of the "D" lens. Thus, when the incident angle is such that the reflected light is 100% polarized parallel to the flat surface of the "D" lens (Brewster's Angle), the horizontal component will be zero.

During the experiment, both the horizontal and vertical components of the reflected light are measured so the horizontal component of interest can be normalized by dividing by the sum of the two components. This gives a percentage of the total reflected light that is horizontally (perpendicularly) polarized.

Each measurement must also be divided by the reference light intensity to account for momentary changes in intensity of the laser light source.

**NOTE**: The laser light is already polarized, but the round polarizer set at 45° solves the problem. To make the relative intensities of the *"p" (parallel)* and *"s" (perpendicular)* components the same, the light is polarized at 45°.

## Sensor Setup

1. Connect the PASCO interface to the computer and start the data acquisition software.
2. If you are using DataStudio, open the DataStudio setup file titled "Brewsters_PASPORT.ds" (for PASPORT) or "Brewsters.ds" (for ScienceWorkshop).
3. Plug the Rotary Motion Sensor and the two High Sensitivity Light Sensors into the interface.

### Set the Light Sensor Range

1. To get full use of the Light Sensor range, set the light sensor range: for a PASPORT sensor, press the "light bulb" button on the side of the sensor and for a ScienceWorkshop sensor, set the "GAIN" switch on the top of the sensor to 100.
2. In the data acquisition program, click "**Start**" and rotate the first round polarizer (nearest to the laser) to allow the light level to be as high as possible without exceeding 95% on the Digits display of the Reflected Light Intensity (measured by the sensor on the Spectrophotometer Arm) and the Reference Light Intensity (measured by the sensor on the second optics bench). Click "**Stop**".

**Note**: If the Reflected Light Intensity is as high as possible without exceeding 95%, but the Reference Light Intensity is *above* 95%, try one of the following to reduce the Reference Light Intensity:

- Slightly adjust the second optics bench from side-to-side so that only *part* of the laser beam enters through slit #5 of the Aperture Disk.
- Rotate the Aperture Disk in front of the second light sensor so that the laser beam enters slit #4 instead of slit #5.

### Zero the Rotary Motion Sensor

1. To zero the Rotary Motion Sensor, first remove the "D" Lens. Adjust the Spectrophotometer Arm if needed so that the laser beam is centered on slit #5 on the Aperture Bracket disk. (The 180° mark on the Spectrophotometer Degree Plate should be near the index line.)
2. Click "**Start**" and slowly move the arm back and forth so that the slit moves through the width of the laser beam. Stop at the position where the Digits display shows maximum intensity.
3. Click "**Stop**" and do not move the arm until you use the program to take the actual data run. (This insures that the zero for the Rotary Motion Sensor is at the center of the laser beam.)
4. Replace the "D" Lens on the lens mount against the step, centering it so the laser beam still shines on slit #5.

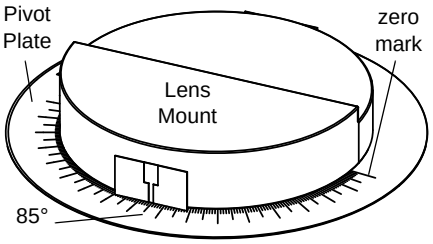
**Note about angle measurement**: The angle of reflection from the "D" Lens is calculated by dividing the actual angle measured by the Rotary Motion Sensor by two. The best procedure is to set the index line on the high side of the Lens Mount to a particular angle (such as 85°) and then move the Spectrophotometer Arm so that the angle shown on the Digits display is the same as the angle of the Lens Mount. Note that to get the laser beam exactly on the #5 slit in front of the Light Sensor, you must make fine adjustments while watching the Digits display for the maximum light intensity. You can adjust either the Lens Mount or the Spectrophotometer Arm until the intensity is maximized.

## Procedure

### Taking Measurements

1. Lighting: Turn off the room lights when making a measurement. (A small light might be useful for seeing the computer keyboard and for putting the Analyzing Polarizer on and off.)
2. Click "**Start**". The "**Start**" button in the toolbar will change to "**Keep**"

. Do not click the red square ("**Stop**") on the "**Keep**" button until all of the procedure steps are completed.




**3.** Remove the Analyzing Polarizer from the Spectrophotometer Arm. Turn the Lens Mount so that the index mark on the high step is at 85° on the Pivot Plate (measured from the zero mark closest to the Beam Splitter).

**4.** Rotate the Spectrophotometer Arm to about 85° (as shown on the Digits display of the Angle), and, while watching the Digits display of the Reflected Light Intensity, adjust the angle of the arm so that the laser beam reflected by the "D" Lens shines on the #5 slit on the Aperture Bracket. (The angle does not have to be exact - just close enough that you get enough light.)

**5.** If the maximum light intensity drops below 50%, adjust the round Polarizer nearest the laser to increase the light intensity above 50%. Do not allow the reference intensity to exceed 95%. (This will make the measurement as precise as possible. Since you are plotting the ratio of polarized intensity over total intensity, changing the total intensity will not affect the ratio. As you proceed it will eventually be impossible to make the maximum intensity above 50%.)

**6.** Place the square Analyzing Polarizer with its axis *horizontal* just in front of the Aperture Bracket on the Spectrophotometer Arm. (**Note**: The Analyzing Polarizer must sit flat on the arm.)

**7.** Press "**Keep**" to record the Angle, the Reflected Light Intensity, and the Reference Light Intensity.

**See "Entering the Data" (next page)**

It is helpful to enter data in the table as it is collected so you can see the progression of data towards the minimum.

*When the polarizer is horizontal, the light passing through the polarizer is polarized perpendicular to the surface of the D Lens. This is the polarized light that is a minimum at Brewster's Angle.*

**8.** Rotate the square Analyzing Polarizer so its axis is *vertical* and set it on the Spectrophotometer Arm just in front of the Aperture Bracket.

**9.** Press "**Keep**" to record the Angle, the Reflected Light Intensity, and the Reference Light Intensity.

*When the polarizer is vertical, the light passing through the polarizer is polarized parallel to the surface of the D Lens. This is the polarized light that is a maximum at Brewster's Angle. Both the horizontal and vertical components are measured so the perpendicularly polarized light can be normalized by dividing by the sum of the two components.*

**10.** Remove the Analyzing Polarizer and set up for the next angle. Rotate the Lens Mount so the index mark lines up with 80°, and move the Spectrophotometer Arm so that the angle in the

Digits display is the same (or close to it). Adjust the Spectrophotometer Arm so the Digits display of Reflected Light Intensity is a maximum.

**11.** Repeat steps 6 through 9.

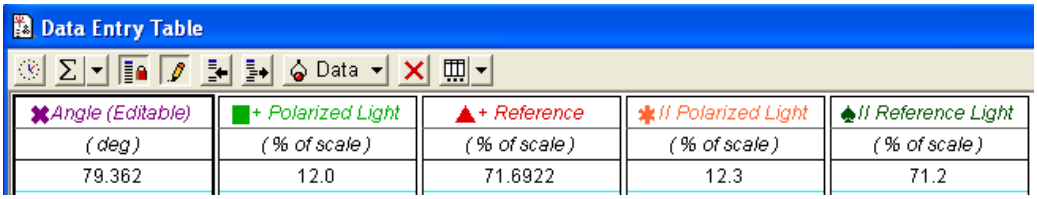
**12.** Continue to repeat the procedure, reducing the angle of the Lens Mount by five degrees until you reach 65°. When the reflected light intensity is approaching the minimum, record data (press "**Keep**") every one degree. When you reach 50°, change the angle by five degrees each time until you reach about 25°.

**13.** Click "**Stop**" to end data recording.

### Entering the Data

It is helpful to enter data in the table as it is collected so you can see the progression of the data towards the minimum.

There will be two sets of data for each angle. The first set is for the perpendicular reflected light (when the Analyzing Polarizer's axis was *horizontal*), and the second set is for the parallel reflected light (when the Analyzing Polarizer's axis was *vertical*). For each angle, read the Reflected Light Intensity and the Reference Light Intensity and enter the values into the Data Entry Table.




**1.** For the first set, type the value of the Reflected Light Intensity into the "**+ Polarized Light**" column. Press "**Enter**" and then type the Reference Light Intensity into the "**+ Reference**" column. Press "**Enter**" after typing the value.

**2.** For the second set, type the value of the Reflected Light Intensity into the "**II Polarized Light**" column. Press "**Enter**" and then type the Reference Light Intensity into the "**II Reference**" column. Press "**Enter**" after typing the value.

### Repeat the Procedure

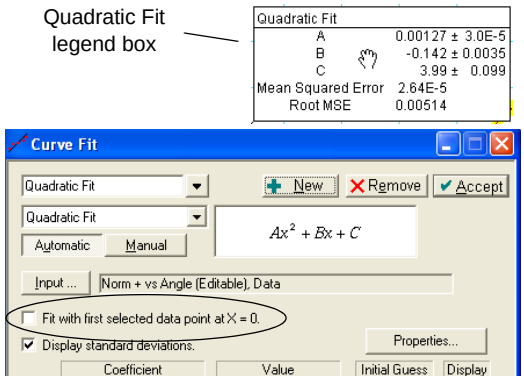
Repeat the procedure for a different wavelength (color) laser.

## Analysis

The DataStudio file that is set up for Brewster's Angle has several built-in calculations that use the perpendicular reflected light intensity, the parallel reflected light intensity, the reference light intensity, and the angle of reflection. The file also has Table displays for recorded data and entered data and a Graph display for determining Brewster's Angle.

**1.** To determine Brewster's Angle, use the Graph display ("Norm +" versus "Angle"). In the Graph, select a group of data points on both sides of the apparent minimum.

**2.** Click the "Fit" menu in the toolbar of the Graph and select "Quadratic Fit". (**Note**: Double click the Quadratic Fit legend box to open the Curve Fit dialog box. Make sure that "Fit with first selected data point at X = 0" is NOT selected.)




## Questions

**1.** From the curve fit, how do you determine the minimum of the function?

**2.** Use Brewster's Angle to calculate the index of refraction of the acrylic "D" Lens using Equation (3) $\tan\theta_p = \frac{n_2}{n_1}$. What value should you use for $n_1$?

**3.** Would Brewster's Angle be larger or smaller for light in air reflecting off water?

**4.** Would Brewster's Angle be larger or smaller for light in water reflecting from the "D" Lens (that is, if the "D" Lens were submerged in water)?

**5.** How do polarized sunglasses reduce glare? Which direction is the axis of polarization in a pair of polarized glasses? How would you check this?

**6.** Which direction is the axis of polarization of the light reflected from the "D" Lens?

**7.** How is the index of refraction affected by a change in the wavelength of the laser?

# Teacher's Guide: Discovering Brewster's Angle

## Sample Data

The Table display "Green Data Collection" shows sample data of Angle, Reflected Light Intensity, and Reference Light Intensity for a green (532 nanometer) diode laser.

Green Data Collection

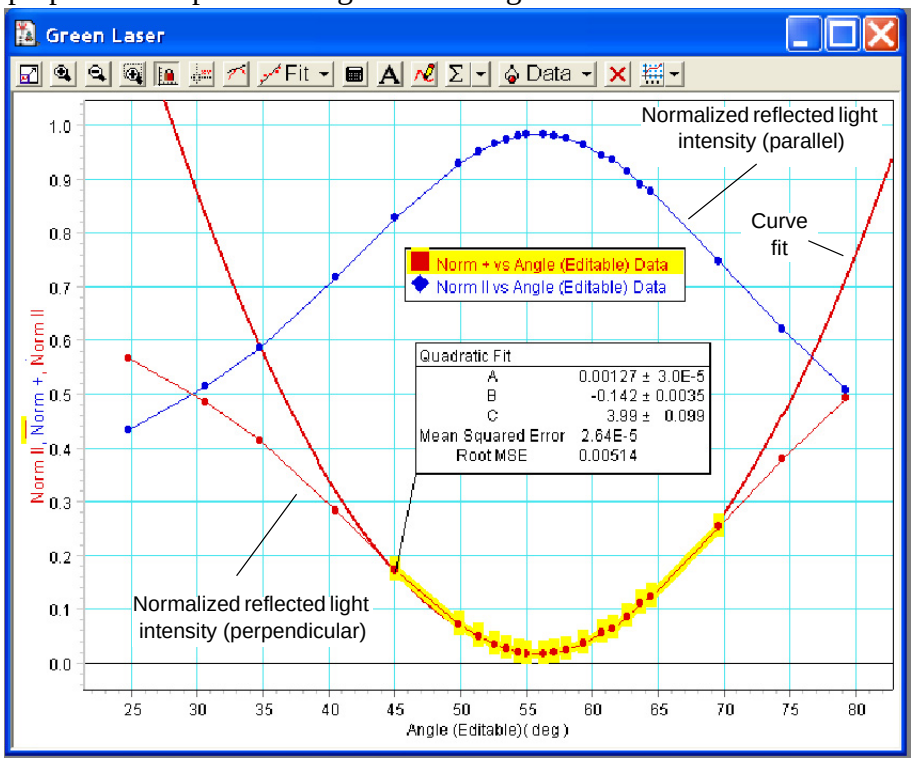
| Angle Run #1 | Reflected Light Intensity Run #1 | Reference Light Intensity Run #1 |
|---|---|---|
| ( deg ) | Light Intensity ( % of scale max ) | Light Intensity ( % of scale max ) |
| 74.5230 | 5.5837 | 70.9572 |
| 74.5230 | 9.1964 | 71.3470 |
| 69.6660 | 2.3223 | 72.1483 |
| 69.6690 | 6.8727 | 72.3824 |
| 64.5030 | 0.7084 | 73.6317 |
| 64.5030 | 5.0813 | 73.0380 |
| 63.7140 | 0.5787 | 73.5902 |
| 63.7140 | 4.6118 | 73.4854 |
| 62.7390 | 0.4240 | 72.4124 |
| 62.7420 | 4.4677 | 72.3175 |
| 61.5960 | 0.2961 | 71.3701 |
| 61.5960 | 4.2859 | 71.2464 |
| 60.7620 | 0.2075 | 71.2533 |
| 60.7620 | 3.5019 | 70.3618 |
| 59.4120 | 0.1316 | 69.7058 |
| 59.4120 | 3.4854 | 69.3154 |
| 58.0380 | 0.0785 | 68.4207 |
| 58.0380 | 3.3643 | 68.6379 |
| 57.1140 | 0.0583 | 67.6379 |
| 57.1140 | 2.9245 | 67.8261 |
| 56.3370 | 0.0498 | 67.8027 |
| 56.3370 | 2.9807 | 67.3425 |
| 55.0860 | 0.0489 | 66.1060 |
| 55.0860 | 2.8195 | 66.4016 |
| 54.3930 | 0.0547 | 67.0916 |
| 54.3930 | 2.6502 | 66.5876 |
| 53.5050 | 0.0684 | 67.0954 |
| 53.5050 | 2.4829 | 67.6626 |
| 52.5810 | 0.0883 | 67.6711 |
| 52.5810 | 2.5624 | 68.8413 |
| 51.3900 | 0.1192 | 68.8212 |
| 51.3900 | 2.2739 | 68.5752 |
| 49.8720 | 0.1668 | 69.0429 |
| 49.8720 | 2.1641 | 68.1177 |
| 45.0600 | 0.3806 | 67.5813 |
| 45.0600 | 1.8138 | 67.2832 |
| 40.5270 | 0.5900 | 67.9849 |
| 40.5270 | 1.4931 | 67.8635 |
| 34.8210 | 0.8550 | 67.0471 |
| 34.8210 | 1.2246 | 67.4765 |
| 30.7230 | 1.0215 | 66.7144 |
| 30.7260 | 1.0798 | 66.5611 |
| 24.7920 | 1.2086 | 66.9200 |
| 24.7920 | 0.9234 | 66.8478 |

The Table display "Data Entry" shows sample data entered into the table and calculated values for "Norm +" and "Norm ||".

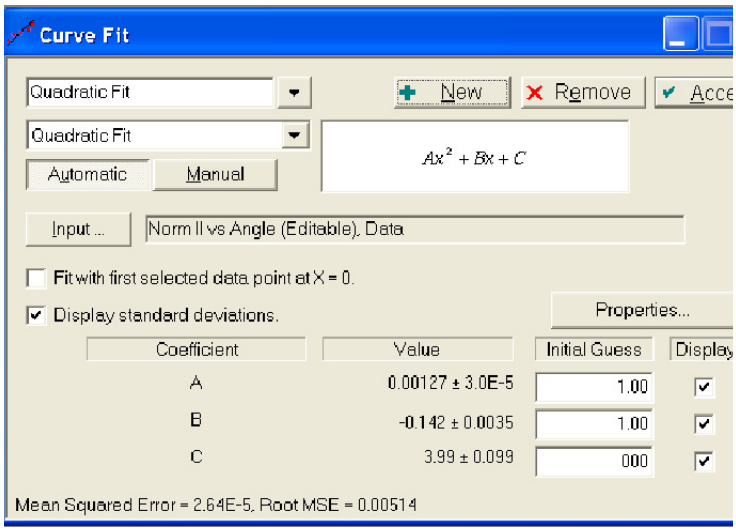
Data Entry

| Angle (Editable) (deg) | + Reference (%) | \|\| Reference Light (% of scale max) | + Polarized Light (%) | \|\| Polarized Light (%) | Norm + | Norm \|\| |
|---|---|---|---|---|---|---|
| 79.362 | 71.6922 | 71.1616 | 12.0021 | 12.2527 | 0.493 | 0.507 |
| 74.523 | 70.9572 | 71.3470 | 5.5837 | 9.1964 | 0.379 | 0.621 |
| 69.666 | 72.1483 | 72.3824 | 2.3223 | 6.8727 | 0.253 | 0.747 |
| 64.503 | 73.6317 | 73.0380 | 0.7084 | 5.0813 | 0.121 | 0.879 |
| 63.714 | 73.5902 | 73.4854 | 0.5787 | 4.6118 | 0.111 | 0.889 |
| 62.739 | 72.4124 | 72.3175 | 0.4240 | 4.4677 | 0.087 | 0.913 |
| 61.596 | 71.3701 | 71.2464 | 0.2961 | 4.2859 | 0.065 | 0.935 |
| 60.762 | 71.2533 | 70.3618 | 0.2075 | 3.5019 | 0.055 | 0.945 |
| 59.412 | 69.7058 | 69.3154 | 0.1316 | 3.4854 | 0.036 | 0.964 |
| 58.038 | 68.4207 | 68.6379 | 0.0785 | 3.3643 | 0.023 | 0.977 |
| 57.114 | 67.6379 | 67.8261 | 0.0583 | 2.9245 | 0.020 | 0.980 |
| 56.337 | 67.8027 | 67.3425 | 0.0498 | 2.9807 | 0.016 | 0.984 |
| 55.086 | 66.1060 | 66.4016 | 0.0489 | 2.8195 | 0.017 | 0.983 |
| 54.393 | 67.0916 | 66.5876 | 0.0547 | 2.6502 | 0.020 | 0.980 |
| 53.505 | 67.0954 | 67.6626 | 0.0684 | 2.4829 | 0.027 | 0.973 |
| 52.581 | 67.6711 | 68.8413 | 0.0883 | 2.5624 | 0.034 | 0.966 |
| 51.390 | 68.8212 | 68.5752 | 0.1192 | 2.2739 | 0.050 | 0.950 |
| 49.872 | 69.0429 | 68.1177 | 0.1668 | 2.1641 | 0.071 | 0.929 |
| 45.060 | 67.5813 | 67.2832 | 0.3806 | 1.8138 | 0.173 | 0.827 |
| 40.527 | 67.9849 | 67.8635 | 0.5900 | 1.4931 | 0.283 | 0.717 |
| 34.821 | 67.0471 | 67.4765 | 0.8550 | 1.2246 | 0.413 | 0.587 |
| 30.723 | 66.7144 | 66.5611 | 1.0215 | 1.0798 | 0.486 | 0.514 |
| 24.792 | 66.9200 | 66.8478 | 1.2086 | 0.9234 | 0.567 | 0.433 |

The Graph display "Green Laser" shows normalized reflected light intensity for parallel and perpendicular polarized light versus angle.



The Curve Fit dialog box for the green laser shows the coefficients of the quadratic formula of the curve fit.




**Curve Fit dialog box for green laser**

## Questions

**1.** From the curve fit, how do you determine the minimum of the function?

To find the minimum, set dy/dx equal to zero for the quadratic formula

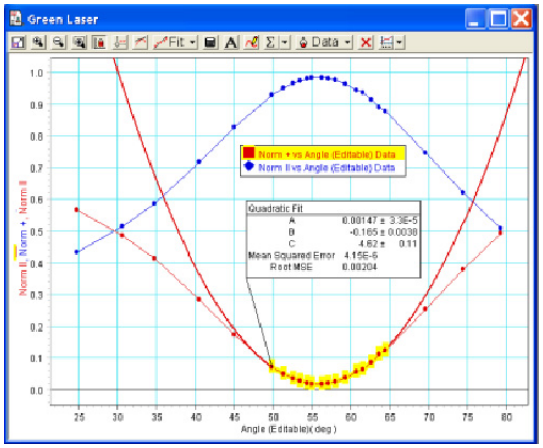
. $\frac{dy}{dx} = 2Ax + B = 2(0.00127) - 0.142 = 0$

Solving for x gives 55.9°.

To estimate the error, use the cursor in the Graph display to select a different set of data points (see the Graph).

The different set of data points gives an angle of 56.1°.

The error estimate is 55.9°±0.2°.




**2.** Use Brewster's Angle to calculate the index of refraction of the acrylic "D" Lens using Equation (3): $\tan\theta_p = \frac{n_2}{n_1}$. What value should you use for $n_1$?

The value of $n_1$ = 1.00 (for air).

$n_2 = n_1 \tan\theta_p = (1.00)\tan(55.9°) = 1.48 \pm 0.01$ for the green laser (wavelength = 532 nm)

$n_2 = n_1 \tan\theta_p = (1.00)\tan(57.3°) = 1.56 \pm 0.01$ for a blue diode laser (wavelength = 405 nm)*

(*See the sample data at the end of this section.)

**3.** Would Brewster's Angle be larger or smaller for light in air reflecting off water?

The Brewster's Angle would be smaller for light in air reflecting off water.

$$\tan\theta_p = \frac{n_2}{n_1} = \frac{1.33}{1} \Rightarrow \theta_p = 53°$$

**4.** Would Brewster's Angle be larger or smaller for light in water reflecting from the "D" Lens (that is, if the "D" Lens were submerged in water)?

The Brewster's Angle would be smaller for light in water reflecting from the "D" Lens.

$$\tan\theta_p = \frac{n_2}{n_1} = \frac{1.50}{1.33} \Rightarrow \theta_p = 48°$$

**5.** How do polarized sunglasses reduce glare? Which direction is the axis of polarization in a pair of polarized glasses? How would you check this?

Glare is polarized reflected light. Since glare is often reflected off horizontal surfaces (such as water), the sunglasses are polarized vertically to extinguish the horizontally polarized reflected light. To check this, you could text the sunglasses with the Analyzing Polarizer since it has a known axis of polarization.

**6.** Which direction is the axis of polarization of the light reflected from the "D" Lens?

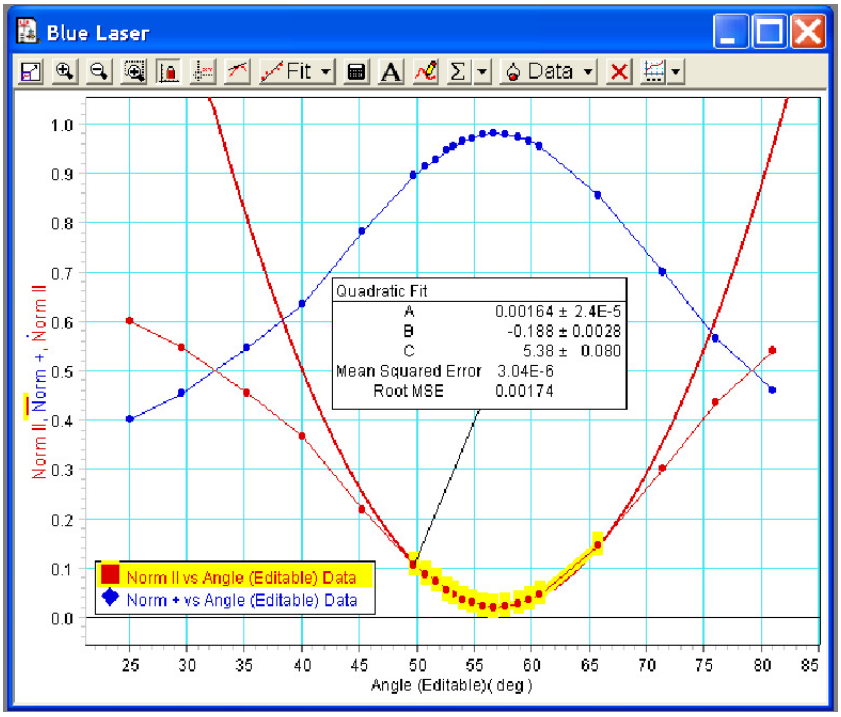
The axis of polarization of the light reflected off the "D" Lens is parallel to the surface, which in this case is vertical.

**7.** How is the index of refraction affected by a change in the wavelength of the laser?

In general, the index of refraction increases as the frequency increases (wavelength decreases).

## Sample Data (Blue Laser)

The following Graph display shows polarized light intensity versus angle for blue laser light having a wavelength of 405 nm.

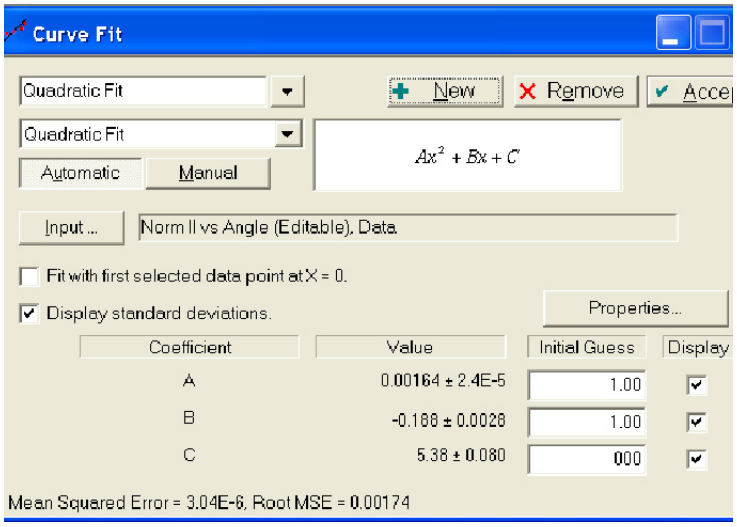



The Curve Fit dialog box for the blue laser shows the coefficients of the quadratic formula of the curve fit.

To find the minimum, set dy/dx equal to zero for the quadratic formula

$$\frac{dy}{dx} = 2Ax + B = 2(0.00164) - 0.188 = 0$$

Solving for x gives 57.3°.




**Curve Fit dialog box for blue laser**

# Further Investigation

## I. Intensity of reflected light (without polarizer)

**Note:** This experiment uses the same setup except the Analyzing Polarizer is removed and you do not need the second optics bench, aperture bracket, and High Sensitivity Light Sensor.

**1.** Reflect the laser beam off the outside plane side of the "D" lens.

**2.** Make a graph of Light Intensity versus Angle where Angle is a calculation:
Angle = (180-abs(x)/15)/2,
where **x** is the Angular Position. (For instructions on creating equations in DataStudio, see Appendix A of this manual.)

**3.** Repeat Step 1 of the procedure for the Brewster's Angle experiment. Then do Step 2, except this time, sweep the Light Sensor on the Spectrophotometer Arm through the reflected laser beam. The result is an intensity peak. Do not stop recording data. Use a Smart Cursor to measure the angle at maximum intensity and the magnitude of the maximum intensity. It is useful to have the graph set on a sliding scale, but if the Smart Cursor is used, you will need to click on "show live data" in the pull down menu to resume the sliding scale.

**4.** Repeat the procedure for angles in increments of 5 degrees.

**5.** Under the "Experiment" pull-down menu in DataStudio, click "New Empty Data Table". Enter the data, and make a graph of Light Intensity versus Angle.

**6.** Repeat the experiment with the laser beam entering the curved side of the lens and reflecting off the inside of the plane side of the lens. This will give the critical angle for total internal reflection.

## II. Intensity of Transmitted Light

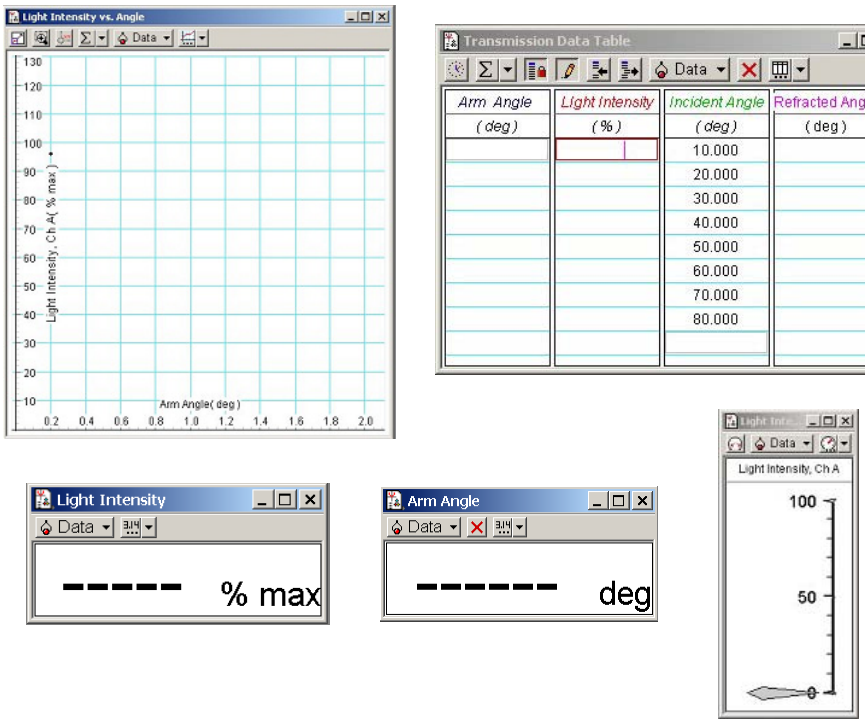
This experiment uses the same setup as part I "Reflected Intensity," but the slits should both be set on #3.

**1.** The computer can measure the refracted angle, but not the incident angle. You must read the markings on Brewster's base and enter them manually.

**2.** Arrange the curved part of the lens so it is towards the laser. Set the Pivot Plates base angle to 10 degrees. Sweep the Light Sensor through the reflected laser beam. The result is an intensity peak. Do not stop recording data. Use a Smart Cursor to measure the angle to maximum intensity and the magnitude of the maximum intensity

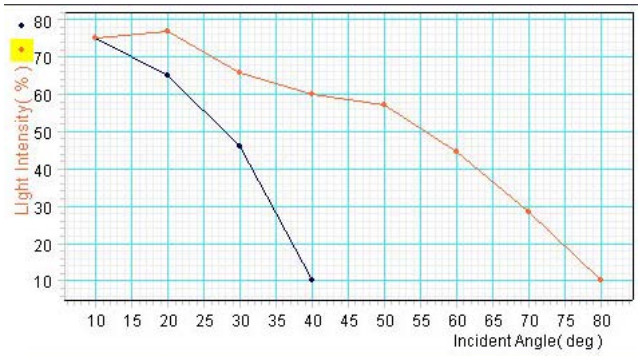
**3.** Repeat the procedure for angles in increments of 10 degrees.

**4.** In DataStudio, set up the displays as shown below.




**5.** Repeat this procedure with the lens turned around. Have the flat side of the "D" lens towards the laser. This will show total internal reflection above angles of about 40 degrees.

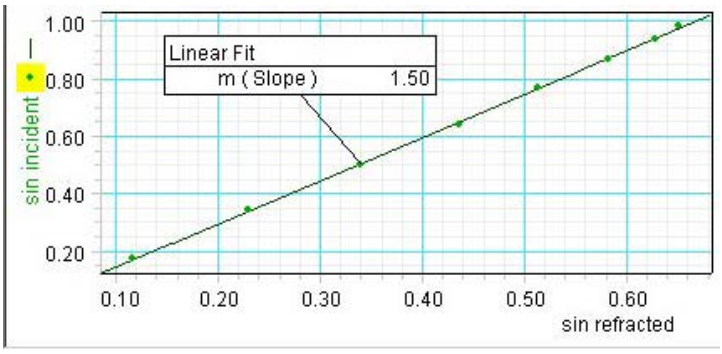
**Sample Data: Light Intensity vs. Incident Angle**



### III. Snell's Law

For the data from the first part of part II, graph Sin (incident angle) vs. Sin (refracted angle). The slope of the line is the refraction index of the acrylic plastic.

**Sample Data: Incident Angle vs. Refracted Angle**




In DataStudio, create the following equations:

a) refracted angle=Oi-x(deg), where **Oi** is the incident angle, and **x** is the arm angle in degrees.

b) sin incident = sin(x), where **x** is the incident angle (degrees).

c) sin refracted = sin(x), where **x** is refracted angle (degrees).

For instructions on creating equations, see Appendix A or the DataStudio online help.

## Acknowledgements

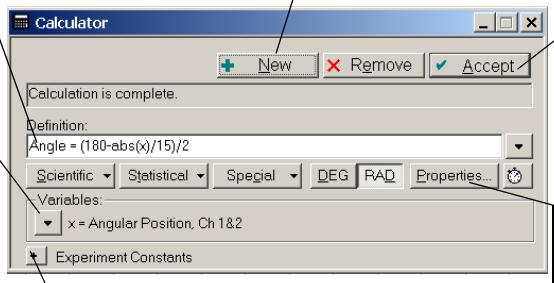
The Brewster's Angle experiment was developed using original ideas from P.J. Ouseph, Professor of Physics at University of Louisville, KY, from an *American Journal of Physics* article titled "Polarization of Light by Reflection and the Brewster Angle", Vol. 69, page 1166 (2001), by P.J. Ouseph, Kevin Driver, and John Conklin.

Modifications to the Brewster's Angle experiment were suggested by Cristian Bahrim and Wei-Tai Hsu in an *American Journal of Physics* article titled "Precise measurement of the reflective indices for dielectrics using an improved Brewster Angle method", Vol. 77, page 337 (2009).

# Appendix A: Creating Equations in DataStudio

**Step 2: Type in and/or build the equation.** (Use the Scientific, Statistical, and Special menus, and the trigonometric functions to build the equation.) Click the **Accept** button.

**Step 1: Create a new equation.** On the main toolbar, click the **Calculate** button to open the Calculator dialog. In the Calculator dialog, click the **New** button.




**Step 6: Save the equation.** Click the **Accept** button.

**Step 3: Define the dependent variables.** Under "Variables," use the down arrow to select a variable or constant, etc. and click OK. (Example: For "x," select "Data Measurement." In the pop-up, select "Angular Position," and click OK.

**Step 5: Label the units.** Click on the **Properties** button to open the Data Properties dialog and enter the name and units. (Example: In the Data Properties dialog, type "Angle" in the name box and "degrees" in the units box.)

**Step 4: Enter any experiment constants (optional).** Use the **(+)** button to create an experiment constant. Click **New**, then enter the name, value and units for the constant. Click the **Accept** button. Go back to the Variables menu and select "experiment constant." Click OK.

**Note:** Each time you build a new equation, click the **New** button. To edit a completed equation, double click on the equation in the Data list, make your changes, and click the **Accept** button to save your changes.

# Appendix B: Laser Safety Information

The OS-8525A Laser Diode is a low power, Class 2 laser. When Class 2 lasers are used in accordance with Occupational Health and Safety Administration (OSHA) standards, Class 2 lasers are not harmful. However, when appropriate safety precautions are not taken, Class 2 lasers can cause permanent, irreversible damage to the eyes. As an instructor, you should always inform your students of the hazards of lasers and the necessary preventative, safety measures.

PASCO cannot be held liable for negligent use in the classroom. As a courtesy, we are providing you with the following laser safety instructions. These reminders are not a comprehensive list of all possible safety measures or hazards. For more information, see the OSHA web site (http://www.osha.gov). Also see http://www.safetymanual.com or www.laserinstitute.org

## Safety Reminders:

- Never look directly into the laser or at any reflection from the laser at eye level.
- Do not point a laser at your own eye, through glass, mirrors or transparent objects in your surroundings, or at the eyes of other individuals.
- Never remove any of the covering or components of the OS-8525A Diode Laser. If the laser is defective, return the defective laser immediately to PASCO scientific.
- If you are uncomfortable or unsure about working around lasers, wear protective laser goggles or spectacles.

## About Laser Protective Eyewear

The eyewear must be designed for use with lasers and meet OSHA standards specific to the type and class of laser you are using. You can tell if the type of goggle or spectacle you are using meets laser standards by looking at the insignia on the side of the frame. Any type of plastic chemical protective goggle will not suffice. Also, you need to select protective eyewear with the correct filter for the wavelength range of the laser (For a Class 2 laser, you need a 400-780 nm filter.)

**Example:** Laser goggles designed to protect for Class 1 lasers do not provide maximum protection when using Class 2 lasers. For more information, see the OSHA web site (www.osha.gov).

## Laser Injuries

Severe corneal injuries or eye burns may or may not present with pain at the surface of the eye. In retinal injuries, the individual may see red spots, or have blurred vision or altered color perception.

Less severe injuries may not show up immediately and are more hazardous when they occur repetitively.

If you believe you have a laser injury, report the injury immediately to your instructor/ supervisor, school health department and/or safety officer. If necessary, go to an emergency health facility or contact a medical doctor or opthalmologist.

# Technical Support

For assistance with the OS-8170A Brewster's Angle Accessory or any other PASCO products, contact PASCO as follows:

Address: PASCO scientific
10101 Foothills Blvd.
Roseville, CA 95747-7100
Phone: (916) 786-3800
FAX: (916) 786-3292
Web: www.pasco.com
Email: techsupp@pasco.com

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## Limited Warranty

PASCO scientific warrants the product to be free from defects in materials and workmanship for a period of one year from the date of shipment to the customer. PASCO will repair or replace, at its option, any part of the product which is deemed to be defective in material or workmanship. The warranty does not cover damage to the product caused by abuse or improper use. Determination of whether a product failure is the result of a manufacturing defect or improper use by the customer shall be made solely by PASCO scientific. Responsibility for the return of equipment for warranty repair belongs to the customer. Equipment must be properly packed to prevent damage and shipped postage or freight prepaid. (Damage caused by improper packing of the equipment for return shipment will not be covered by the warranty.) Shipping costs for returning the equipment after repair will be paid by PASCO scientific.

**Written by**:

Ann Hanks